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III. *A description of an extensive series of the Water Battery; with an Account of some Experiments made in order to test the relation of the Electrical and the Chemical Actions which take place before and after completion of the Voltaic Circuit.* *By* JOHN P. GASSIOT, *Esq., F.R.S.*

Received December 7, 1843,—Read January 25, 1844.

1. IN a paper, which I communicated to the Royal Society in 1839, and which was honoured by insertion in the Transactions of the following year, I described a series of experiments made with some powerful voltaic batteries, for the purpose of determining the possibility of obtaining a spark *before* the completion of the voltaic circuit. I was therein enabled to establish a few facts respecting polar tension, or rather respecting the absence of any notable degree of it in the batteries I described*; for instance, I proved that, with 320 series of Professor DANIELL's constant battery, polar tension was not evinced adequate to the striking distance of $\frac{1}{5000}$th of an inch; nor was I more successful in obtaining it with a water battery of 1024 series†, constructed by the same gentleman. I also stated that, according to the present theoretical views of the action of the voltaic battery, with the apparatus I then used, it ought to have taken place; and that, if by a still more powerful apparatus it could not be obtained, the theory must, in some way or other, be incorrect.

2. The preceding negative facts are not without their value in a scientific point of view; they show us, at least, a certain limit within which the anticipated effects could not be obtained. At the same time I could not fail to admit that they were anything but conclusive, as to the actual question of the possibility of obtaining the spark before the circuit was completed. That I am justified in calling the spark, under such circumstances, an anticipated effect, may be fairly assumed, because every electrician is aware that the terminals of a voltaic series invariably evince a certain amount of tension‡; and as spark is but a consequence of tension exalted to a maximum, it is only fair to anticipate that, by increasing the tension, it would be obtained.

3. A short time after the publication of the paper to which I have alluded, a communication reached me from my friend Mr. CROSSE, of Broomfield, Somersetshire, wherein he stated that, with 1626 cells of copper and zinc, excited with river water, he had succeeded in obtaining a spark between slips of tinfoil pasted on sealing wax. This communication I immediately forwarded for publication in the Philosophical Magazine for September 1840.

* Philosophical Transactions, 1840, p. 184, § 10. † Ibid. § 15. ‡ Ibid. § 14.

4. I was at that time engaged in the construction of an extensive series of the water battery; but, from the difficulties of insulation, which continually presented themselves, considerable time elapsed before the battery was in a condition to afford results, on which any dependence could be placed. Having, at length, to a certain extent, surmounted these difficulties, I have been enabled especially to study the character and action of the water battery, and through it, I may hope, of the voltaic battery generally. The results of my experiments, with a description of the apparatus used, may, I think, not be uninteresting to the electrician, particularly as they establish the fact, beyond any doubt, of not only the passing of a distinct spark before the completion of the circuit, but the practicability of continuing this action for several weeks in constant succession, and enabling us to examine, with much accuracy, the rationale of the action of this extraordinary apparatus.

5. The water battery, which I have constructed, and which I am about to describe, consists of 3520 pairs, or series of copper and zinc cylinders, each pair being placed in a separate glass vessel, well covered with a coating of lac varnish. The glass cells are placed on slips of glass, covered on both sides with a thick coating of lac; this coating being fixed by heating the glass over a gas furnace, and then covering it with the varnish. The 3520 cells, thus insulated, are placed on forty-four separate oaken boards, also covered with lac varnish, each board carrying eighty cells. The boards, or trays, slide into a wooden frame, where they are further insulated by resting on pieces of thick plate glass, similarly varnished.

6. It may at first sight appear that many of these precautions are unnecessary; in truth, had I, at the outset, expected they would have been requisite, I might probably have been deterred from attempting so troublesome and lengthened an inquiry. At first I imitated the apparatus of Mr. CROSSE, already referred to (3.), the copper cylinders being made water-tight that they might themselves constitute the cells; and considering such insulation would be sufficient, I attached the cells to the boards with sealing wax, poured into holes made in the boards for the insertion of each cell. I found this arrangement answer very well for a few hundred series, but when the number was augmented, and the battery completed, the insulation was sadly deficient. This induced me to take the battery asunder, and to have distinct or separate glass vessels made for each pair. After again completing the entire series, I found the insulation was even less efficient than before; for from the glass attracting moisture from the atmosphere, as well as from the evaporation of the battery, each cell became a conductor, and scarcely any effect could be produced on the *electroscope*; in fact, it was not until I had finally adopted the arrangements I have previously described, that any approximation to a tolerable insulation could be maintained.

7. The general appearance of the battery may be seen by referring to Plate I. fig. 1, where A, A′ represent the wooden frames, in which are placed the forty-four boards containing the entire battery; B a shelf on which a galvanometer can be placed, or any other apparatus for the detection of a current or chemical action.

Fig. 4.

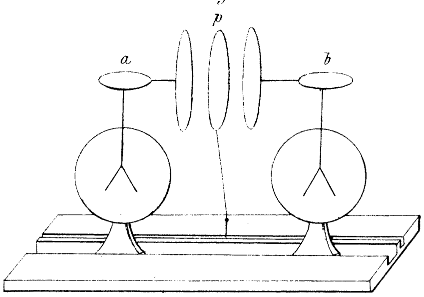


Fig. 5.

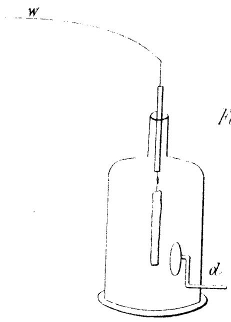


Fig. 2.

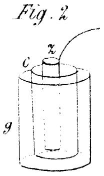


Fig. 1.

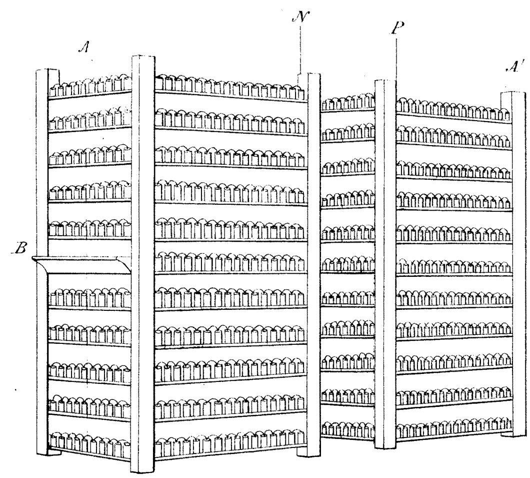


Fig. 3.

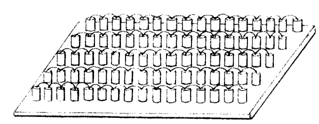


Fig. 6.

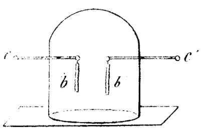


Fig. 7.

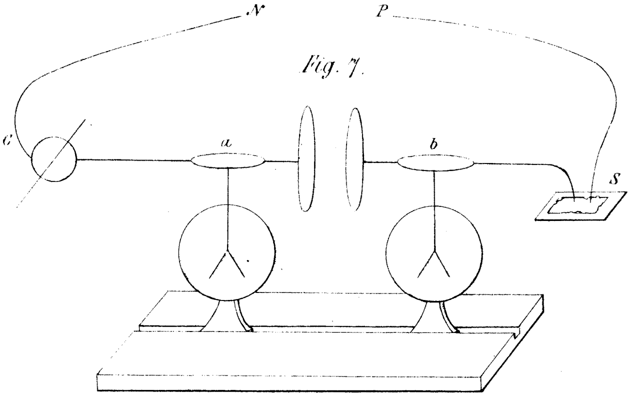
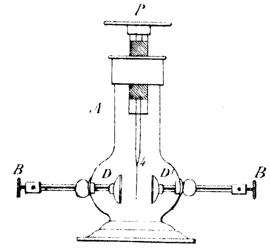


Fig. 8.



N and P are the terminals or poles of the battery. Fig. 2 is a single cell; *g*, a glass vessel; *c*, copper; *z*, zinc. Fig. 3, one of the boards as it appears when removed from the entire series. Fig. 4, a double electroscope. Fig. 5, a HARRIS's single-leaf electroscope. Fig. 6, another electroscope, having two separately insulated gold leaves, $b\,b'$: in addition, I used a delicate galvanometer, and a solution of iodide of potassium for the detection of currents and of chemical action. The battery was charged, by carefully filling each cell with rain water.

8. With all the precautions I have described, the insulation of the battery was still imperfect; and, from the experience which I have gained during the construction of this apparatus, I have little hesitation in asserting, that the very nature of the water battery must prevent the experimentalist from obtaining insulation for any lengthened period, when such an extended series is employed.

9. In proceeding to describe the effects which this apparatus has presented, I must endeavour to draw a distinct line of demarcation between the *static* and the *dynamic* effects; for although these are, in a certain sense, both associated in some forms of electric development, yet as I have been enabled in a degree to isolate them here, it is my intention to regard them separately.

10. We know, from the very earliest experiments, that the extremities of a voltaic pile present opposite electrical states; it is therefore stating no new fact, to say that when one extremity of the series is connected with the ground, the other, on being connected with a gold-leaf electroscope, indicates a high degree of electric tension, and that the gold leaves diverge with considerable energy. Indeed, in the battery above described, there was little need of making connection with the ground; for, with all my precautions, I found the insulation was in a short time very imperfect, and that, by this communication with the earth, a complete circuit, to a certain extent, already existed.

11. As the *static* effects present themselves antecedently to the *dynamic*, they necessarily demand the first notice. The entire battery was connected in one series, and copper wires from the extreme cells were connected with the plates *a* and *b* of the double electroscope (fig. 4); this instantly produced a considerable and steady divergence of the gold leaves; and, on applying the usual tests, the plate *b*, connected with the copper extremity, gave signs of vitreous, and *a*, connected with the zinc, of resinous electricity. If *a* was connected with one extremity of the battery, and the other extremity was connected or not with the ground, the same general effects occurred; the divergence of the leaves corresponded with the connection, and the leaves of *b* diverged by induction; if, in this state, *b* was touched and then removed from the influence of *a*, it was found charged with the opposite electricity.

12. These inductive effects were obtained under other forms; for instance, the condensing plate (*p*), which had been removed during the preceding experiments, was opposed to the charged plate *a*. When *a* alone was connected with the battery, and *p* was touched, while under the influence of induction, and then removed,

p was found oppositely charged; as was also an insulated carrier ball, when similarly treated.

13. The plate *a* of the electroscope (fig. 4) being retained in connection with one end of the battery, a piece of very thin mica was laid on it; on this mica rested a wire W proceeding from a single-leaf electroscope (fig. 5), the disc (*d*) of which was in connection with the earth by means of a wire; with this arrangement the gold leaf was electrified by induction, and struck against the disc (*d*); glass, lac and sulphur were in turn substituted for the mica, and the same general effects resulted. The same battery connection was maintained, the electroscope (fig. 5) being disconnected. An insulated carrier ball was successively applied to the plate *a*, and an unlimited succession of charges could be carried and accumulated to another electroscope: these charges were with equal facility obtained when the *direct* connection between the battery and the earth was broken; the insulation of the battery was, however, comparatively imperfect; and I shall therefore have occasion to revert to some of these results which I afterwards obtained less in degree, but equally definite in character, from a portion of the battery detached for the purpose of more efficient insulation; for the present we need only allude to those effects, which do not absolutely involve the perfect insulations of the battery itself. When a Leyden jar, held in the hand, was subjected to the action of one end of the battery, a charge was readily accumulated, and, of course, still more favourably by means of a mica battery. When the coatings of a Leyden battery, consisting of twelve jars, with a surface of sixteen feet, were connected with the respective ends of the series, the accumulation of tension was considerable.

14. With the entire battery, the tension was so great, that the leaves of a gold-leaf electroscope diverged when that instrument was placed within two or three inches of either end of the battery, or over any of the terminal cells. Advantage was taken of this to test, whether any effect of tension could be observed when the circuit was completed; but the instant this was effected, the leaves of the electroscope as instantly collapsed, nor could I detect, either by the aid of the condenser, or otherwise, the slightest trace of tension; it, however, immediately reappeared when the circuit was again broken.

15. Thus far I have been examining the *static* effects of a moderate amount of tension, similar in kind to those which have been long familiar to the electrician, but modified so as to produce inductive effects, differing in some degree from any elsewhere recorded. My first experiment, after making every allowance for loss of electricity, or, as it would be better to express it, loss of tension through insufficient insulation, admits but of one interpretation: the interpretation itself is generally allowed, but the force of it is not, I believe, generally admitted; it is, *that the elements constituting the voltaic battery, when arranged in series, assume polar tension before the circuit is completed*; and that in the apparatus above mentioned, this tension is such *that a spark will pass before the circuit is completed.*

16. When the micrometer electrometer, described in my former paper*, was introduced between the terminal wires, sparks, through the space of $\frac{1}{50}$th of an inch, were obtained; and when the double electroscope (fig. 4) was included in the circuit, and the discs *a* and *b* were approximated, an uninterrupted succession of sparks would pass between the discs. These effects, which I have repeatedly shown to many friends, are most brilliant. On one occasion they were continued uninterruptedly day and night for upwards of five weeks; and although some months have now elapsed since this battery was completed, it still exhibits the same effects.

17. When the experimenter was standing on the ground, and consequently, as has been already explained, in actual, although imperfect connection, with the battery, he could draw sparks from either terminal. We shall, in the sequel, be enabled to trace, with more precision, the rise of this tension; for the present, we are only concerned in establishing its existence, and thereby proving the first fact, that *tension* or *electrostatic effects precede, and are independent of, the completion of the voltaic circuit.*

18. Hitherto we have not obtained any insight into the condition of the *dynamic* effects under such circumstances of antecedent tension. For testing the presence of what is usually termed the current, or in other words, obtaining the means of observing the electro-dynamic effects, I used the instrument which is best suited for examining such phenomena, and which invariably attests the instant completion of a voltaic circuit. An exceedingly delicate galvanometer was introduced at B (see fig. 1), and the two condensing plates *a* and *b* of the double electroscope (fig. 4) were respectively attached by wires to the terminals N and P of the battery, fig. 1. If great care was taken not to make any connection with the ground, the party manipulating being himself well insulated on shell-lac, no action could be perceived on the needle in the galvanometer, although the gold leaves of the electroscope immediately diverged to a very considerable extent.

19. This experiment was, however, of too much importance to be passed over without adopting every means of making it unexceptionable. Two trays from the battery, being a series of 160 cells, were removed and insulated, by being supported on stout varnished glass pillars twelve inches high; the whole being placed upon an ARNOTT's stove in which a fire had been kept burning for several hours. The galvanometer was interposed between the zinc terminal of one tray and the copper terminal of the other; and the extremities of this reduced series were arranged so as to exhibit the same effects of electric tension which we have seen in the entire series; but not the slightest indication of dynamic action could be detected by the galvanometer. The action of the instrument I used could not be in fault; and some idea may be conceived of its extreme delicacy, when I state that, with one cell of the gas battery† I have obtained a steady deflection, whilst a resistance of twelve miles of thin copper wire was interposed in the circuit; when the electroscope (fig. 6) was used, *c c'* being respectively connected with N and P of battery, the gold leaves *b b'*, were attracted;

* Philosophical Transactions, 1840, p. 184, § 12.

† Ibid. 1843.

and the moment they touched each other, the needle of the galvanometer was deflected.

20. The best definition that occurs to me of a current is that given by FARADAY in his Third Series of Experimental Researches*. "By current I mean anything progressive, whether it be a fluid of electricity, or two fluids moving in opposite directions, or merely vibrations; or, speaking still more generally, progressive forces;" and in juxtaposition to this, he says†, "If the magnetic effects depend upon a current, then it is evident they could not be produced in any degree before the circuit was complete, because prior to that no current could exist." Now it is manifest that, in the experiments already mentioned, the voltaic elements have the power of exhibiting electric effects at either, and both ends or terminals, before any progression or actual perceptible force takes place in the course of the series; in other words, that *static* effects exist before or independently of currents, but that these effects cease immediately on currents being developed.

21. But, in an inquiry like this, we must examine more closely the actual chemical action; for it involves much of the source of controversy between the contact and chemical theories; and I was naturally anxious to discover whether simultaneously with these *static* effects, or perhaps antecedently to them, *any chemical action took place in the cells of the battery*; and if so, to what amount.

22. FARADAY‡, in the course of that branch of his experimental researches which introduced into notice the voltameter, established the most accurate means of measuring the amount of chemical action in the battery cells, by the equivalent amount of chemical decomposition exhibited in that instrument; he has also directed our attention to the fact, that this amount of electro-chemical decomposition depends essentially on the current as denoted by the galvanometer. There was every reason, with these facts before us, to expect that the battery, which did not produce a current, would not evince any degree of chemical decomposition. Recourse was, however, had to the test of experiment; and, instead of introducing the galvanometer, I substituted for it a small piece of bibulous paper, saturated with a solution of iodide of potassium; the gold leaves of the electroscope diverged as before, but, however long the duration of action, not the least indication of the liberation of iodine was perceptible. The inference I make from this is, that no definite chemical action took place in any cell of the battery, and consequently that the *electric effects* above shown, and which are termed *static* effects, take place *before* or *independently of the actual development of the chemical effects*.

23. I am aware that, in some form or other, this fact has been acknowledged by the most strenuous advocates of the chemical theory. BECQUEREL§ thus adverts to it:—"We must conclude, from all the electrical phenomena, that, in almost all cases, a chemical action has taken place; and hence we are led to believe that the latter is the cause which exercises the greatest degree of influence over their production; nevertheless,

* Experimental Researches, § 283. † § 282. ‡ § 510. § Traité de l'Elect., vol. ii. p. 145; vol. v. p. 3.

in the present condition of science, we must not yet abandon VOLTA's theory, since it may very readily happen, that, at the contact of two bodies, a disengagement of electricity may take place, resulting from a commencement of chemical action between these bodies."

DE LA RIVE*, who has laboured perhaps more than any of the continental philosophers in advocating the chemical origin of voltaic electricity, cannot but admit some such similar qualification, as may be seen from the following extract from one of his papers:—"The two theories between which philosophers are divided with respect to the origin of voltaic electricity, are still the subject of lively controversy; when we are adverting to the pile itself and to hydro-electric currents, we cannot deny the superiority of the chemical theory; the recent labours of FARADAY have, moreover, added powerful arguments in favour of this theory; but it must be acknowledged that it is not easy to defend it when we advert to electricity of tension developed in the contact of two heterogeneous bodies, especially if the two bodies are solid."

FARADAY†, who has recently instituted a series of elaborate researches in support of the chemical theory, writes thus of it:—"The theory assumes that the particles of the di-electric (now an electrolyte) are, in the first instance, brought by ordinary induction into a polarized state, and raised to a certain degree of tension or intensity before discharge commences, the inductive state being in fact a *necessary preliminary* to discharge." Again, "One point is, that different electrolytes or di-electrics require different initial intensities for their decomposition. This may depend upon the degree of polarization which the particles require before electrolytic discharge commences‡."

GROVE§, in a recent communication to the Royal Society, in allusion to the action of the gas battery, says, "If, indeed, the contact theory assume contact as the efficient cause of voltaic action, but admit that this can only be circulated by chemical action, I see little difference, save in the mere hypothetical expression, between the contact and chemical theories; any conclusion which would flow from the one would likewise be deducible from the other; there is no observed sequence of time in the phenomena, the contact or completion of the circuit and the electrolytical action are synchronous. If this be the view of contact theorists, the rival theories are mere disputes about terms. If, however, the contact theory connects with the term *contact* an idea of force which does or may produce a voltaic current independently of chemical action, a force without consumption, I cannot but regard it as inconsistent with the whole tenor of voltaic facts and general experience."

24. I shall have occasion to revert to the gas battery, the action of which is fully described in the paper from which I have taken the preceding quotation; but the action we are now examining is not that arising from *contact or completion of the circuit*, but that which is caused by contact in the arrangement of a progressive

* Archives de l'Electricité, vol. i. p. 619.

† Experimental Researches, § 1345.

‡ Ibid. § 1354.

§ Philosophical Transactions, 1843.

series of the elements of a voltaic battery *previous* to the circuit being completed; such progressive arrangement being indispensable for the production of the effects we are now examining, or the production of certain forces in a given direction. A mere heterogeneous assemblage of the elements will not produce the effects; on the contrary, any alteration in the regular series produces a corresponding reduction of force, and any number of batteries arranged—copper, liquid, zinc,—will exactly neutralize the action of a similar number arranged,—zinc, liquid, copper.

25. The question I am now examining is, however, not whether contact produces current, but whether it produces electric development, and whether that development is accompanied by any chemical action; and this necessarily involves the question, whether the effects of current, or those usually called voltaic, have the same efficient cause as the electro-static. That certain effects can be produced independently of any *apparent* chemical action, is not merely proved by experiment with the water battery, but it is further confirmed by many unexceptionable experiments; among those for which I may particularly claim attention, are those of M. PECLET, who in describing them says, "I have only had in view static electricity developed by contact, I have not troubled myself about currents when the circuit is closed*."

26. The examination of M. PECLET's experiments, the investigation of the action of the voltaic series generally, and more particularly of the water battery, seem to lead to the inference that elective affinity is greatly concerned in the *antecedent* action, of which chemical combinations, when the circuit is closed, are the *consequence.* I might quote the particular experiments of M. PECLET as an evidence of static effects having been obtained without any apparent chemical combination; but, without attempting to follow out what may, perhaps, somewhat fairly, be assumed as hypothetical cases, viz. those in which tension does not appear to terminate in chemical action, *let us trace the process by which tension rises in an insulated pile, and the still further process necessary to establish a current.*

27. Two trays of the battery were carefully insulated as before (19.): if in this state one of the piles is touched by the hand, its electric tension is apparently destroyed, the leaves of the electroscope in connection collapsing; whilst those of an electroscope attached to the other terminal obtain their extreme divergence. If this battery be now left to itself, the end which has been touched regains a certain amount of tension, and the leaves of the other electroscope collapse in proportion: generally, the means of raising the tension of one extremity of the battery is to touch the other. I do not mean to assert that the tension of the end which was touched is entirely destroyed, but certainly with 160 series, for the space of several seconds, I could not with the most delicate gold-leaf electroscope obtain the slightest indication of it.

28. MARIANINI went through a series of experiments, in which he found that in no case was tension actually destroyed; but that it fell in proportion to the duration of the time during which the circuit had been completed. My object now was not, however,

* Archives de l'Electricité, vol. i. p. 622.

to complete the circuit; for I wished to test an intermediate stage between actual insulation and actual completion of circuit, in order to discover the character of the discharges effected by touching the respective terminals, or rather their influence over the state of tension, into which the whole series was thrown. I wished, for instance, to discover whether the discharge I effected, threw the elements of the battery *back*, into the normal condition which prevailed antecedent to the discharge; or whether it threw them *forward* by completing the act of chemical combination, the preparatory state of which already existed; whether, for instance, mere discharge, either by the earth or by completion of the circuit, for an instant, is one small fraction of a current; and, if so, whether a current is not really a collection of discharges of electricity of tension.

29. For this purpose the following experiments were made: a copper wire attached to N of the battery was connected with the galvanometer, and this with the plate *a* of the double electroscope, fig. 4. A platinum wire was attached to P of the battery, the end of which rested on a piece of bibulous paper saturated with a solution of iodide of potassium: another platinum wire, also resting on the paper, was connected with the other plate *b* of the electroscope; by the mechanical arrangement of this instrument, the plates could be approximated or separated as required. Fig. 7 shows the arrangement; N and P, the terminals of the battery; G, the galvanometer; *a* and *b*, the plates of the electroscope; S, solution of iodide of potassium.

30. When the plates *a* and *b* were approximated so as to permit sparks to pass at intervals of about a second, a *tremulous* motion was imparted to the needle; but when they were brought so nearly in contact as to permit the discharges to take place in quick succession, the needle was *steadily* deflected, and iodine freely evolved; proving that chemical action was occurring in each cell, and that the current is a collection or an accumulation of discharges of electricity of tension; for although the circuit was completed by distinct and separate discharges, still the deflection of the needle was as steady as if the discs had been in actual metallic contact.

31. The discs *a* and *b* were then separated to the distance of about an inch; a piece of tinfoil was suspended by means of a thread of white silk; the tinfoil vibrated between the plates, but no effect could be produced on iodide of potassium or on the galvanometer.

32. I have already alluded to the extreme difficulty I experienced in effecting perfect insulation. I was anxious to ascertain whether this insulation, and at the same time a high state of intensity, could be obtained, and whether, in such a state, any evidence of chemical action could be detected when one end of the battery was in connection with the ground. After many trials, I succeeded in insulating 320 cells; and so efficient was even this reduced number in point of intensity, that sparks could be obtained by means of the micrometer electrometer through a space of $\frac{1}{1000}$th of an inch. The ends of two platinum wires were then fixed so as to rest on a piece of bibulous paper saturated with a solution of iodide of potassium. One of the

wires was connected at one time with the copper, and at another time with the zinc terminal of the battery; while the wire attached to the other extremity was connected with the earth. This arrangement being continued for several hours, and the paper kept constantly moist, not the slightest evidence of any evolution of iodine could be detected, until by a momentary contact made with the further extremity of the battery and the ground, either by a wire, or by touching it with the hand, the circuit was completed. Here we have a voltaic battery the intensity of which is sufficient to elicit a *spark* between its terminals before the circuit is completed, but in which antecedent thereto, the slightest chemical action is not appreciable; and this when one end is in connection with the earth, and consequently having the intensity exalted to a maximum short of actual discharge.

33. I am aware of the many forms the contact theory has assumed since VOLTA first propounded it; nor can we lose sight of the many errors which his successors have committed in attempting to follow out their favourite views of metallic contact and electro-motive forces. I am indebted for much information on this point to the kindness and industry of Mr. C. V. WALKER, who has occupied much time in procuring me references to the researches of those electricians already alluded to, as also to a long list of others whose names adorn the pages of science. I could easily have added to those I have named, by referring to the experiments of many other authors who consider that their favourite theory of contact has been fully established. It is not, however, my object to advert to these speculations: we have before us certain facts connected with the action of the voltaic battery; first *contact*, or successive juxtaposition, and simultaneously with it, effects of *tension*; then the completion of the circuit, and simultaneously with it, *development of chemical action* and *current*; but in all these cases contact is first in order, developing tension. BECQUEREL describes it by stating, "When two bodies are in contact the affinities commence exercising their action before combination takes place." M. DE LA RIVE, "The electricity of tension developed by contact of heterogeneous bodies." FARADAY, "That the particles of the electrolyte are brought into a polarized state, and raised to a certain degree of tension, before discharge takes place:" but I am not aware that there are any *experimental* facts to prove whether this tension in the voltaic battery, which itself is of an opposite character at each terminal, and, as we have seen, can be exalted so as to produce discharges in the form of sparks for many weeks' constant duration (16.), is due to the chemical constituents of the battery, or to mere contact of dissimilar bodies, without reference to their chemical affinities. I was therefore most anxious to see whether some experiment could not be devised, which would test the action in a satisfactory manner, and for this purpose I availed myself of an extended series of GROVE's gas battery, described by him in a paper already alluded to (23.)*.

34. The elements used in this form of the voltaic battery consist of two gases and one metal; with fifty series charged with oxygen and hydrogen, it is stated that the

* Philosophical Transactions, 1843.

gold-leaf electroscope was notably affected. The instrument used by Mr. Grove, whose original experiments I had the pleasure of witnessing in the laboratory of the London Institution, was the same as is represented in fig. 6. Nothing can be more decisive than that the *static* effects of the voltaic battery are not due to the contact of dissimilar *metals*; as in this arrangement, only one metal, platinum, is used; but this battery, whose action is, in itself, so purely chemical, presents to us a full corroboration of the *static effects preceding the development of chemical action.*

35. A series of forty cells, the same as are described in Mr. Grove's paper*, were charged with oxygen and hydrogen; these sensibly affected the gold-leaf electroscope, fig. 3. This arrangement was kept charged for upwards of three months. No decrease in the gas of the oxygen tubes could be detected. Whenever the terminals were tested by the electroscope, they invariably exhibited the usual signs of tension; but not the slightest chemical or dynamic effect could be obtained until the entire circuit was completed.

36. Here we have a battery, the active elements of which are two gases, which, with a closed circuit, immediately enter into active chemical combination; remaining for upwards of three months in such a state of tension as at all times to affect the leaves of an electroscope; but in which no amount of chemical action could be detected whilst the circuit remained open.

37. It now became a matter of some interest to ascertain, *first*, the minimum amount of series with which the gas battery charged with oxygen and hydrogen would exhibit static effects; and, *secondly*, whether, when it was charged with gases which do not enter into chemical combination, *any* signs of tension could be elicited.

38. By careful arrangement I obtained an attraction in the gold leaves of the electroscope (fig. 6) with a series of nine pairs; with twelve or fourteen, the effects are very distinct, and required no very delicate manipulation. The series of forty pairs was then charged with oxygen and nitrogen; at first the electroscope was affected, and chemical action as well as dynamic effects were obtained with the closed circuit; these, however, were evidently due to impurities in the nitrogen (this gas was obtained by burning phosphorus in common air; the oxygen by electrolysis): after keeping the circuit closed for two days, these effects ceased, when not the slightest static, chemical or dynamic actions could be detected; the volumes of the gases remaining perfectly stationary, whether the circuit was closed or open.

39. From the preceding experiments we learn that, when the gases used in this battery are oxygen and hydrogen (which will from their affinity for each other enter into chemical combination), a series of ten or twelve is sufficient to develope static effects; but that, when charged with gases which have not this power, viz. oxygen and nitrogen, even a series of forty does not affect the electroscope.

40. The advantage of using oxygen and hydrogen is, that although the hydrogen is slightly absorbed by local action with the atmospheric air in the solution, action

* Philosophical Transactions, 1843, plate 5. fig. 1.

does not take place in the oxygen tubes until electrolysis commences; and we have thus the most correct means of defining our results.

41. With hydrogen and chlorine, signs of tension were obtained with a series of six pairs of cells.

42. With chlorine in a single tube, and amalgamated zinc as the positive element, a combination by which, as GROVE has shown*, one pair will decompose water, a series of two pairs affected the electroscope.

43. Having thus elicited that for the purpose of obtaining static effects with a gas battery, it is indispensable that the two gases employed be capable of entering into chemical combination with each other, and having found that the higher the state of their mutual chemical affinities, the less was the number of series required to produce static effects, my attention naturally reverted to the older forms of the voltaic battery. I allude to those having two metallic elements excited by acid solutions.

44. Ten of the glass cells of the water battery (5.) were filled with dilute sulphuric acid. In each cell I placed a small porous earthenware vessel, also filled with the same solution. The metallic elements in this arrangement were amalgamated zinc and platinum; the latter being placed in the porous vessels, each cell was carefully insulated. This arrangement affected the leaves of the electroscope (fig. 6), while it required sixteen series of the water battery (5.) to produce the same effect.

45. The dilute acid was then removed from the porous vessels, and these were refilled with strong nitric acid, forming the well-known nitric acid battery of GROVE. Three series of this arrangement affected the electroscope, and with the assistance of a ZAMBONI's pile, *distinct signs of tension could be elicited from a single pair*; the platinum showing vitreous and the zinc resinous electricity.

From the preceding experiments it appears, that to obtain evidence of tension, the principal requisite is good insulation, and that this condition being fulfilled, the most energetic chemical battery will exhibit signs of tension before the completion of the circuit with a smaller series than that which is merely excited with rain water (44. 45.).

Conclusion.

The deductions which I make from the experiments described in this paper are as follows:—

1st. That the elements constituting the voltaic battery assume polar tension before the circuit is complete (10. 11. 15.) even in a single cell (45.); and that the existence of this polar state is demonstrated by the action on the electroscope being different at each terminal of the battery.

2nd. That this tension, when exalted by a series of pairs, is such, that a succession of sparks will pass between the terminals of the battery before their actual contact (16. 32.).

3rd. That these static effects precede, and are independent of, the completion of

* Philosophical Transactions, 1843, p. 103, Note.

the voltaic circuit (10. 11. 17.), as well as of any *perceptible* development of chemical or dynamic action (18. 19.).

4th. That when the circuit is completed, whether by actual contact of the terminals, or merely by approximating them, so as to allow a succession of sparks, the dynamic effects on the galvanometer are the same (30.); each producing a steady deflection of the needle; consequently that the current, even when the circuit is closed, may be regarded as a series of discharges of electricity of tension, succeeding each other with infinite rapidity.

5th. That the rise of tension in a battery (the chemical affinities of its elements being feeble, as in the water battery) occupies a measurable portion of time (27.).

6th. That to produce *static* effects in the voltaic battery, it is indispensable that the elements should be such as can combine by their chemical affinities (34. 35.), that the higher those chemical affinities are exalted, the less is the number of elements required to exhibit the effects of tension (38. 39. 41. 42. 44 and 45.), and consequently, that the *static* effects elicited from a voltaic series are direct evidence of the first step towards chemical combination or dynamic action.

The chemical effects, when obtained in the generality of the experiments described in this communication, are of course feeble; but they are precisely the same in character as those exhibited by the more powerful voltaic combinations; and it may fairly be concluded that the rationale of each is the same, and that they only differ in the degree of action.

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Note.—I have recently constructed an instrument, by means of which the tension in a single series of the voltaic battery can with facility be tested without the aid of Zamboni's pile. Fig. 8 represents the electroscope, in the construction of which I was in a great measure indebted to an apparatus described by Dr. Hare*. A is a glass vessel, the stem of which is well-coated with lac; B, B′, two copper wires passing through glass tubes and corks; D, D′, gilt discs, each about two inches diameter, attached to the wires; P, a copper plate with a wire passing through a glass tube; to the end of the wire is attached a *narrow* strip of gold leaf, L. The discs must be adjusted with care, so as to allow the leaf to be equidistant from each. If B is connected by a wire attached to the platinum, and B′ by another wire attached to the zinc of a single cell of the nitric acid battery, insulated on a plate of lac, and an ex-

* Silliman's Journal, vol. xxv.

cited glass rod is approximated very gradually towards the plate P, the gold leaf will be attracted to B′, or the disc attached to the zinc; and if excited resin is approximated in a similar manner, the leaf is then attracted to B, or the disc attached to the platinum. By means of this instrument, my friend, the Rev. CHARLES PRITCHARD, obtained signs of tension in a single cell excited by dilute sulphuric acid with platinum and zinc. This experiment I subsequently verified, and obtained similar results with single cells of other usual arrangements of the voltaic battery; but in all the experiments I made, the higher the chemical affinities of the elements used, the greater was the development of the evidence of tension.

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